DISTORTION IN ELECTRON LENS

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Plate VIII

ABSTRACT. The distortion produced by an electromagnetic lens of an electron microscope has been measured in different parts of the image field. From the data obtained, the distortion coefficient of the lens has been evaluated, and compared with similar values obtained by other workers.

1. INTRODUCTION

It is a familiar experience to all workers in electron microscopy, that at low settings of the projector lens, the final image is seen to suffer from pincushion type of distortion. A set of electron micrographs of a 200 mesh metal grid is reproduced in figure 1. Here the projector lens power and hence the magnification increases from left to right. Pincushion distortion is seen to be very prominent in frames of lower magnifications where the peripherial

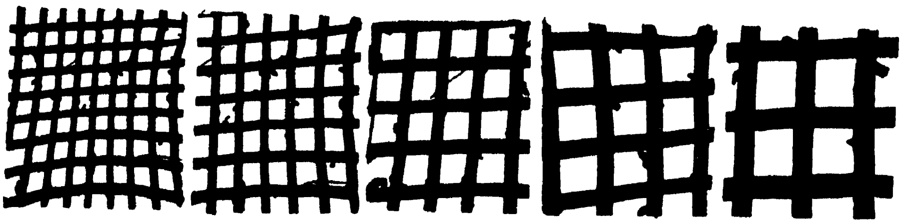

Fig. 1

meshes are found to have elongated shapes. At low magnifications, therefore, the distorted image gives an erroneous representation of the shape and size of the object being imaged.

Occasions, however, often arise, *e.g.* for working with fairly large specimens, when one is constrained to work at low projector magnifications in order that the whole of the magnified image may remain within the final field of view. Under such conditions a knowledge of the amount of distortion in different zones of the image field is of essential importance in order to get a correct appraisal of the true size and shape of the specimen under examination.

An estimation of distortion is also of importance in lens designing in that by experimenting on pole-pieces of various designs, one can find out from the experimental data the values of the distortion coefficient of different pole-pieces. By correlation of values of distortion coefficient with the lens parameters one can ascertain the optimum design parameters for pole-pieces of minimum distortion.

2 THEORETICAL CONSIDERATIONS

In electron microscopes using only one projector lens besides the objective, the distortion is contributed solely by the projector lens (Zworykin *et al*, 1948). The aberration, resulting in a lateral shift of an image point from its true geometric position, can be expressed thus (Zworykin *et al*, 1948) :

$$dr = S_p(M_0 r_0)^3 \tag{1}$$

where dr is the displacement on the final field of view of the image point whose conjugate distance from the optic axis referred to the object plane is r_0, S_p is the coefficient of distortion and M_0 is the magnification due to the objective lens. Since the lens field has rotational symmetry, the displacement is mostly in the radial direction.

The magnitude of distortion can be found out by following the method of Hillier (1946) with a little modification. The method is briefly as follows: The specimen chosen is a replica of a grating whose constant is accurately known. Let O be the point of intersection of the optic axis of the projector lens on the final field of view (figure 2). The co-ordinates XOX' and YOY' are

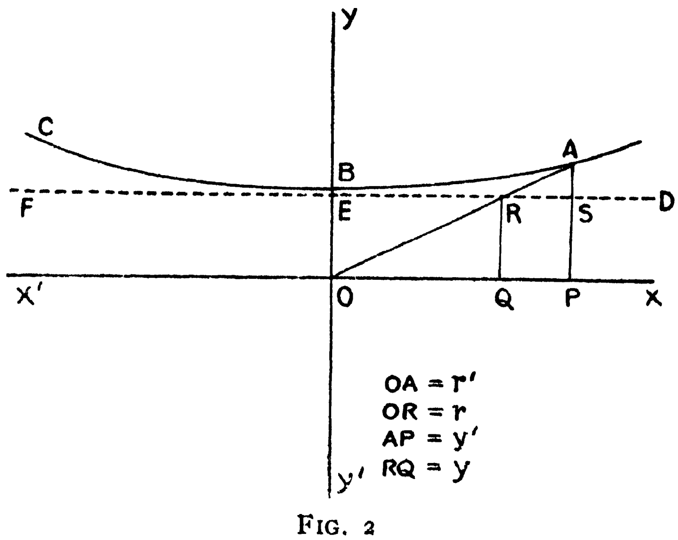

FIG. 2

drawn such that the X-axis lies along the direction of the grating lines on the final field of view. The specimen is moved about and locked so that one grating line lies on and along the X-axis. Let ABC be another grating line which has suffered distortion, and let DEF be the line which would have been the geometric position of ABC had there been no distoration. An arbitrary point A on ABC is joined with O. Since the distortion is mostly radial, the point R is the true geometric position of point A. Calling the distances RQ, AP, OR and OA as respectively y, y', r and r', it follows from the geometry of the figure that

$$r = r', y/y' \qquad (2)$$

If ABC, the line chosen is the n^{th} line from the centre, and if the grating constant G_c and overall magnification M of the microscope be known, then evidently,

$$y = n, G_c M \qquad (3)$$

r' and y' in expression (2) are directly measureable on the final field of view or can be measured conveniently on a micrograph. Hence r in expression (2) *i.e.* the true undistorted distance corresponding to r' is found out. The difference $r' - r = dr$ is the amount of distortion corresponding to the observed image point A situated at r' as seen in the final image. By choosing systematically several image points, their true geometric positions and their corresponding amounts of distortion can therefore, be easily found out. By plotting r and dr against r', curves are drawn to give immediately the distortion in the various zones of the final image field.

From the results thus obtained the coefficient of distortion is ascertained as follows : Since $dr = S_p(M_o r_o)^3$ and $r = M_o M_p r_o$ we have,

$$dr = S_p(r/M_p)^3 \qquad (4)$$

where M_o and M_p are the objective and projector magnifications respectively. Since dr corresponding to r is already ascertained, S_p can be calculated if M_p is known. An accurate knowledge of M_p is therefore required to be known. Then, by plotting dr against (r/M_p) a straight line can be drawn, whose slope gives the value of S_p.

3. EXPERIMENTAL METHOD AND RESULTS

(*i*) *Magnitude of distortion*:

A collodion replica of a grating of constant 1.85μ was mounted on a microscope grid. By proper manipulation of the object stage movement, a grating line was made to lie such that a straight grating line was obtained at the centre on the final field of view. Micrographs were then made and the beam voltage and the objective and projector currents were noted. A typical micrograph is reproduced in Plate VIII.

The microscope was then calibrated with polystrene latex for overall magnification with these voltage and currents. This magnification multiplied by the grating constant, gave the magnitude of the spacings for a distortion-free geometric image, from which the value of y in expression (3) was found out. The values of r' and y' were determined from the grating micrograph.

determined. The value of r/M_p was then calculated, from which, by substituting in expression (4), S_p was found out. dr was next plotted against $(r/M_p)^3$ and a mean straight line was drawn (figure 4). The slope of the line gave the coefficient of distortion S_p, which was found to have the value of 6.42×10^3.

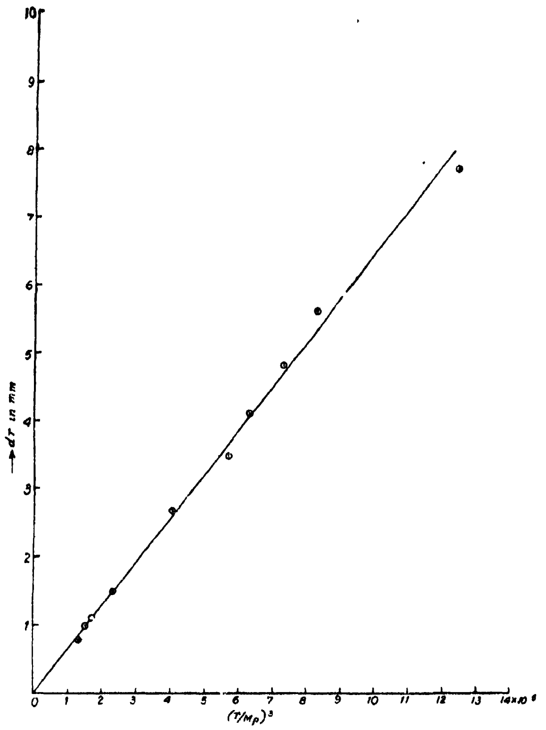

FIG. 4

DISCUSSION

From figure 3 which gives both r anb dr as a function of r' one can ascertain at a glance the true geometric position of an image point whose apparent position is known on a micrograph or on the fluoscent screen, and also the amount of distortion. These two curves therefore are of immediate practical importance. From curve II in figure 3 which gives the distortion as a percentage, it is found that the distortion remains to within 10% upto a distance of 2.5 cm. from the centre.

If, after Zworykin *et al* (1948) it is assumed that S_p can be expressed by a formula of the following type viz.,

$$S_p = M_p . C/D^2 \qquad \ldots \quad (5)$$

where C is a lens constant, we can determine the value of C of our lens from the knowledge of D, the clear diameter of the pole-piece, and M_p, the lens magnification. For our case, $S_p = 6.42 \times 10^3$, $D = 0.195$ cm., $M_p = 65$, so that $C = 3.75$. This value is to be compared with the value of 2.2 estimated by Zworykin *et al* (1948) for a cylindrical lens.

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